AN ULTRA-COMPACT MARX-TYPE HIGH-VOLTAGE GENERATOR*

D. Goerz, T. Ferriera, D. Nelson, R. Speer, M. Wilson
Lawrence Livermore National Laboratory
P.O. Box 808, Mail Stop L-153
Livermore, CA 94550 USA

Abstract

This paper discusses the design of an ultra-compact, Marx-type, high-voltage generator. This system incorporates high-performance components that are closely coupled and integrated into an extremely compact assembly. Low profile, custom ceramic capacitors with coplanar extended electrodes provide primary energy storage. Low-inductance, spark-gap switches incorporate miniature gas cavities imbedded within the central region of the annular shaped capacitors, with very thin dielectric sections separating the energy storage capacitors. Carefully shaped electrodes and insulator surfaces are used throughout to minimize field enhancements, reduce fields at triple-point regions, and enable operation at stress levels closer to the intrinsic breakdown limits of the dielectric materials. Specially shaped resistors and inductors are used for charging and isolation during operation. Forward-coupling ceramic capacitors are connected across successive switch-capacitor-switch stages to assist in switching. Pressurized SF_6 gas is used for electrical insulation in the spark-gap switches and throughout the unit. The pressure housing is constructed entirely of dielectric materials, with segments that interlock with the low-profile switch bodies to provide an integrated support structure for all of the components. This ultra-compact Marx generator employs a modular design that can be sized as needed for a particular application. Units have been assembled with 4, 10, and 30 stages and operated at levels up to 100 kV per stage.

I. INTRODUCTION

Marx generators are frequently used in many pulsed power applications. Usually, they are employed to energize pulse forming sections that can deliver greater peak power to lower impedance loads than the Marx can itself. Most often, these Marx units are constructed with standard, commercially available components, arranged as compactly as possible.

For certain applications, Marx generators can be used to directly power some apparatus or device. For these applications, overall system performance can be significantly improved by employing an ultra-compact Marx generator comprised of specially shaped components assembled into an integrated package. We have developed such devices for various applications.

II. DESCRIPTION

The ultra-compact Marx is depicted in Figure 1. It is a sophisticated electrical device and elaborate mechanical

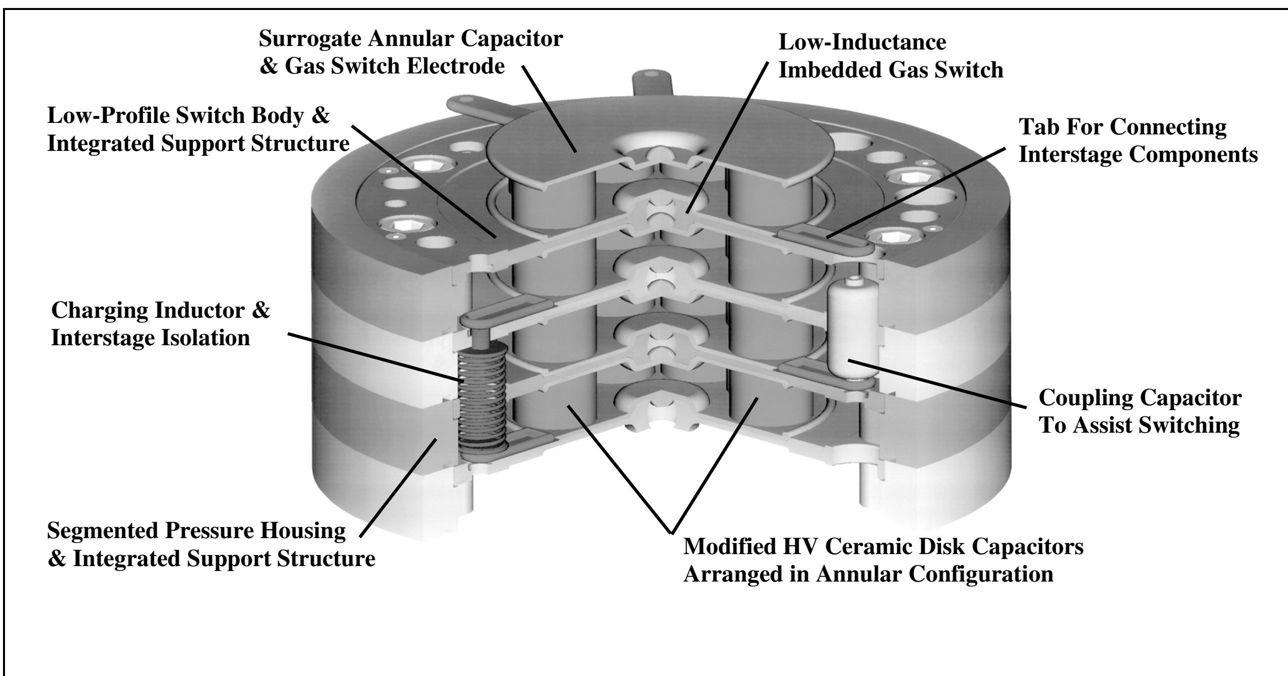

Figure 1. Cutaway-view drawing of the ultra-compact Marx showing key components and integrated packaging.

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14. ABSTRACT
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assembly [1].

Each energy storage capacitor assembly is made up of eight remanufactured disk capacitors arranged in an annular configuration. The 440-pF, 40-kV, N4700-type disk capacitors are modified as shown in Figure 2 to a final height of 1.7 cm. Then they are assembled between extended coplanar electrodes that help maintain uniform

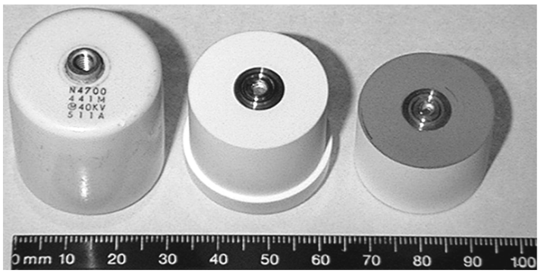

Figure 2. Modifications to commercial disk capacitors.

fields at the triple point regions. Each capacitor assembly is tested to 120 kV in SF_6 before usage. At the elevated operating level of 100 kV, the electrical stress in the ceramic substrate is 60 kV/cm and the effective capacitance is reduced to about 65 percent of normal [2].

The surrogate annular capacitor electrodes also serve as the gas switch electrodes. They are precisely machined to the same shape as the dielectric switch body. Figure 3 shows how the capacitor and switch become an integral unit. The main portion of the switch body that separates

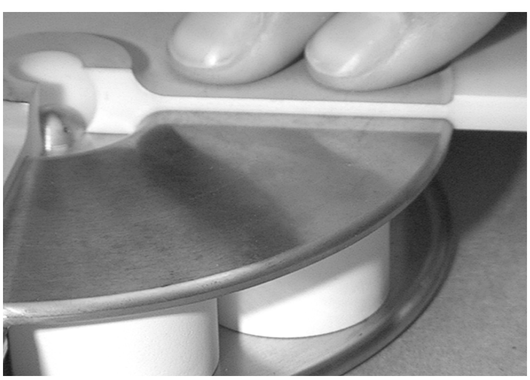

Figure 3. Cutaway view of switch body positioned on top of mating electrode of surrogate annular cap.

the adjacent surrogate annular caps is only 2-mm thick for charge levels as high as 100 kV.

In the central region of the annular cap assembly, a recessed area is formed where the miniature spark gap switch is imbedded. The switch is comprised of raised button electrodes formed on the annular capacitors that protrude into the gas cavity within the dielectric switch body. The cavity wall is contoured to reduce the electric field at the triple points. SF_6 gas has been used to achieve the highest operating levels. Figure 4 shows the operating curve of a typical gas switch having a 2.43-mm gap [3,4].

For such a compact Marx, even the arrangement of charging components becomes difficult. We elected to use a bipolar charging configuration with +50kV and –50kV power supplies connected through coaxial cables to linear strings of custom charging components.

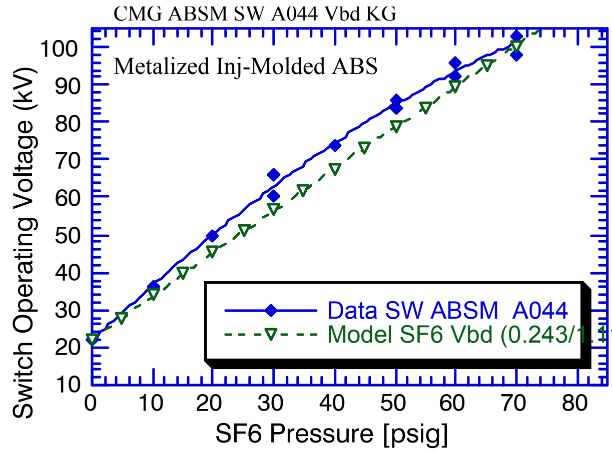

Figure 4. Operating curve of miniature gas switch.

Both resistors and inductors were developed for charging the ultra-compact Marx and providing interstage isolation during operation. Figure 5 shows both types of components. Each is capable of withstanding the 200-kV impulses over their nominal 3-cm length when operated in a pressurized SF_6 environment. Figure 6 shows the arrangment of the resistors in the Marx along with the tabs used to connect to the sides of the energy storage capacitors.

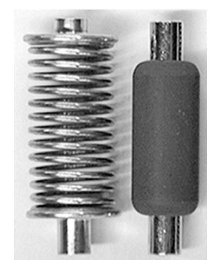

Figure 5. Charging inductor and resistor.

Also shown in Figure 6 is the arrangement of feed-forward coupling capacitors. Ordinarily, in conventional Marx generators, the switch capacitance is low enough that stray stage-to-housing capacitance is adequate to couple enough voltage across adjacent

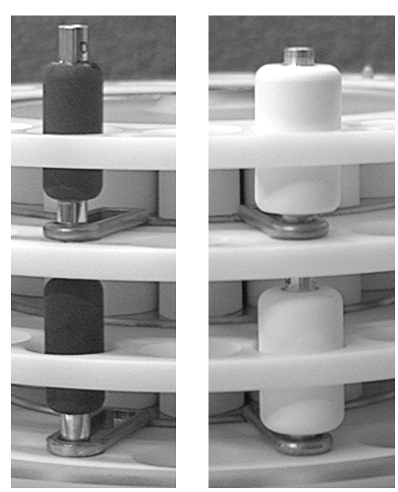

Figure 6. Arrangement of charging resistors (left) and interstage coupling capacitors (right).

switches to cause them to operate. However, in an ultra-compact Marx generator the extremely low-profile switch has such high capacitance that stray coupling is not sufficient. This shortcoming can be overcome by incorporating discrete coupling capacitors connected across stages. In the arrangement shown, the capacitors have no voltage across them when the Marx is charged, but see transient voltages up to 200 kV when the Marx operates. We used commercially available 140-pF 40-kV encapsulated ceamic capacitors, machined somewhat to adjust length and radius edges.

Assembly of the ultra-compact Marx is a process of

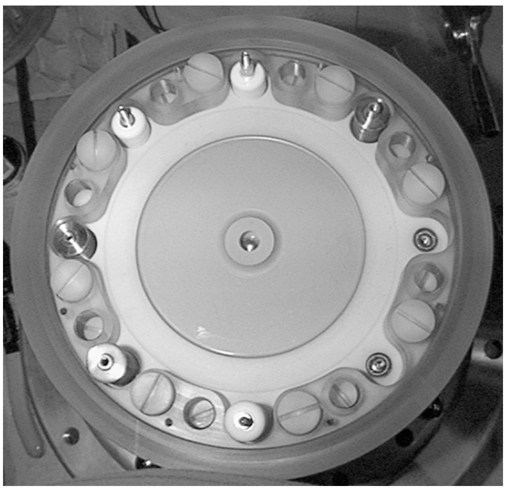

Figure 7b. Next sequential assembly step.

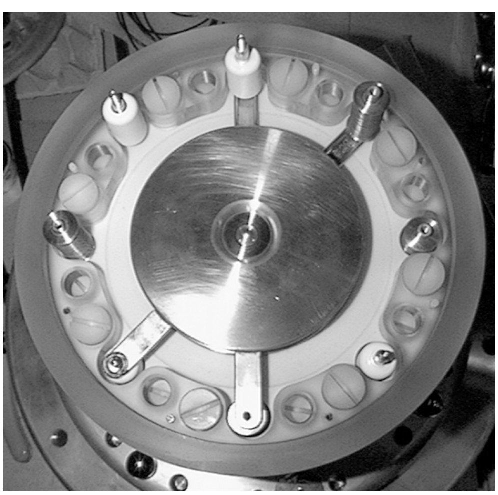

Figure 7a. Intermediate assembly step.

stacking adjoining components and interlocking them with sections of a segmented pressure housing. Figures 7a and 7b show two sequential assembly steps.

III. TEST RESULTS

Prototype units of various sizes have been built and tested. The largest to date is a 30-stage unit that is 75-cm long. Figure 8 shows an open shutter photo taken during a test. The pattern of illumination at each stage is caused by light from each spark gap channeling through the clear dielectric switch body and backlighting the outboard components. The load is comprised of eight 400-ohm liquid resistors running alongside the unit.

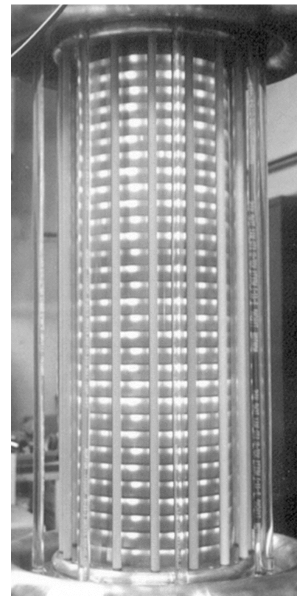

Figure 8. Photograph of 30-stage Ultra-Compact Marx during operation

As designed, operation of any single switch should be sufficient to cause the adjacent switches to self-break. Allowing the weakest switch to selfbreak works quite well. Several methods for triggering have been explored. One uses a trigger pin built into the bottom switch. Another employs trigger pulses coupled through the charge lines to the next in-line switch. Figure 9 show the voltage on the charge lines for such a case.

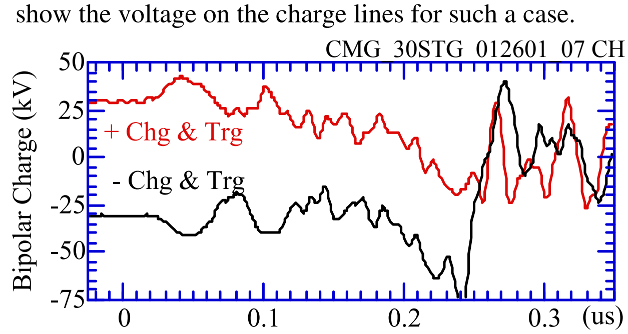

Figure 9. Voltage on charge lines during triggering.

Figure 10 shows a representative output pulse from the prototype 30-stage Marx driving a resistive load. The risetime of the erection process is controlled by the feed-forward coupling capacitors and is comparable to the overall system response. Short circuit testing has also been done to determine system response and compare with cicuit modeling. The ultra-compact Marx

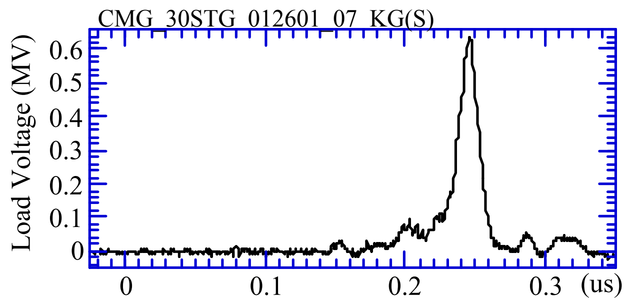

Figure 10. Output voltage into 50 ohm resistive load

can be charged and operated in either polatity, and is capable of withstanding a full voltage reversal.

Further testing is planned to fully evaluate an characterize the performance of the ultra-compact Marx. Figures 11 and 12 show preliminary information from one series of tests covering the middle portion of the operating range.

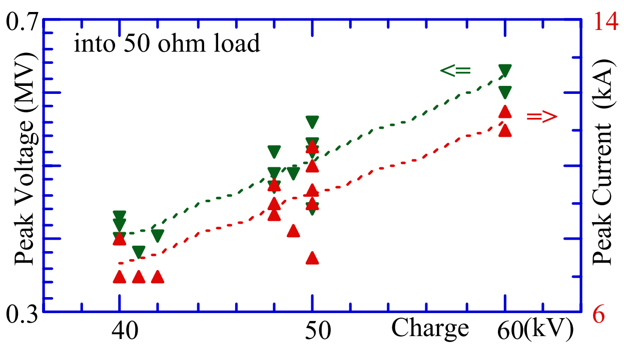

Figure 11. Scaling of peak output levels with charge.

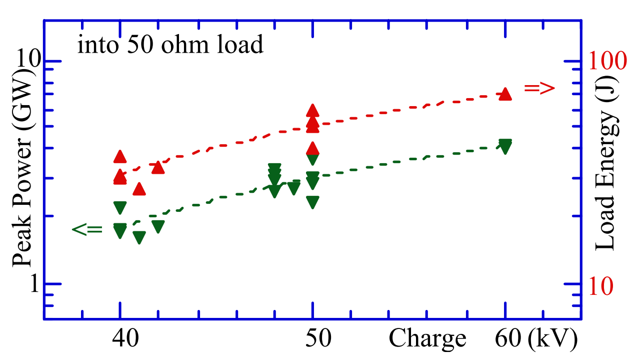

Figure 12. Scaling of output power and energy

IV. SUMMARY

An ultra-compact Marx-type high-voltage generator has been developed and tested. Custom, low-profile components have been devised to achieve performance levels 3 to 5 times higher than normal. An integrated packaging approach has produced an extremely compact assembly and overall high performance.

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